DEVELOPMENT OF A LATERAL, OPPOSED-CONTACT PHOTOCONDUCTIVE SEMICONDUCTOR SWITCH*

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Abstract

Photoconductive Semiconductor Switch (PCSS) development has been performed for many years by various researchers and institutions. The goal of our PCSS development effort is to produce devices with greater hold-off voltage, faster risetimes, and greater lifetime. The PCSS has many applications in pulse power, ranging from ultra-wideband sources to drivers for Q-switches. In this paper the results from a continuing PCSS development effort will be reported. Information covered in this work includes PCSS hold-off voltage data for devices switching in different encapsulating dielectric media. Also, a performance comparison of PCSS devices that have been fabricated on different thickness semi-insulating Gallium Arsenide substrates will be made.

I. INTRODUCTION

In a collaborative effort with the Air Force Research Lab (AFRL), the Naval Surface Warfare Center (NSWC) has been continuing the development of a PCSS device. The goals for this particular PCSS device are hold off voltages in excess of 100kV/cm, sub-nanosecond risetimes, long switch life times, and a physical package to meet the current needs of AFRL.

Due to physical requirements of a proposed AFRL system, the original PCSS had to be shrunk from 18 mm x 14 mm down to 9 mm x 14 mm. The lateral contact separation was maintained at 0.25 cm. To meet the first goal for this development effort a means to increase the hold-off voltage was needed. Hence we approach the first part of the development by increasing the gap spacing with wafer thickness without changing the overall size of the PCSS footprint.

The previous PCSS development effort, from which this work is based, produced a PCSS configuration that has a risetime in the sub-nanosecond regime. But in the early effort, the PCSS device was operated in a dielectric surrounding of SF_6 gas. While SF_6 gas has excellent voltage hold off capabilities, it does little to remove excess heat from the PCSS device. In an effort to remedy this problem an experiment involving liquid dielectrics was proposed. A liquid dielectric that can provide a stable thermal environment for the PCSS while retaining the high field and risetime performance achieved with SF_6 is the goal of this particular experiment.

Long lifetimes are also a goal of this development project. To date the best result for the 0.25-cm lateral PCSS has been 10^5 shots, while most devices that have been tested had lifetimes of 10^4 shots. The goal is to achieve greater than 10^6 shots per device. Lifetime will be addressed in a future phase of this development effort.

II. PCSS CONFIGURATION

The PCSS configuration is the same as that developed by W.R. Buchwald *et. al.* [1]. This configuration features a lateral-opposed contact geometry. This contact geometry makes it possible to increase the gap spacing without changing the PCSS footprint. By simply using thicker wafers, the contact spacing can be increased thus allowing for greater hold off voltages. Three different wafer thicknesses were used for this part of the investigation, 0.85 mm, 1.0 mm, and 2.0 mm.

The leading edge of the contacts have a Rogowski profile and are made with a refractory metal scheme for both the anode and the cathode [2]. The lateral gap spacing for all devices tested was held to 0.25 cm. All devices were fabricated on 2-inch diameter semi-insulating Gallium Arsenide wafers. Fig.1 shows a photo

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14. ABSTRACT
Photoconductive Semiconductor Switch (PCSS) development has been performed for many years by various researchers and institutions. The goal of our PCSS development effort is to produce devices with greater hold-off voltage, faster risetimes, and greater lifetime. The PCSS has many applications in pulse power, ranging from ultra-wideband sources to drivers for Qswitches, In this paper the results from a continuing PCSS development effort will be reported. Information covered in this work includes PCSS hold-off voltage data for devices switching in different encapsulating dielectric media. Also, a performance comparison of PCSS devices that have been fabricated on different thickness semiinsulating Gallium Arsenide substrates will be made.

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of a completed wafer on which several PCSS devices have been made. A total of eight complete devices are shown. The photolithography mask set used for the contact patterning was designed to be used with either 2-inch or 3-inch diameter wafers, hence the partial devices along the perimeter of this wafer.

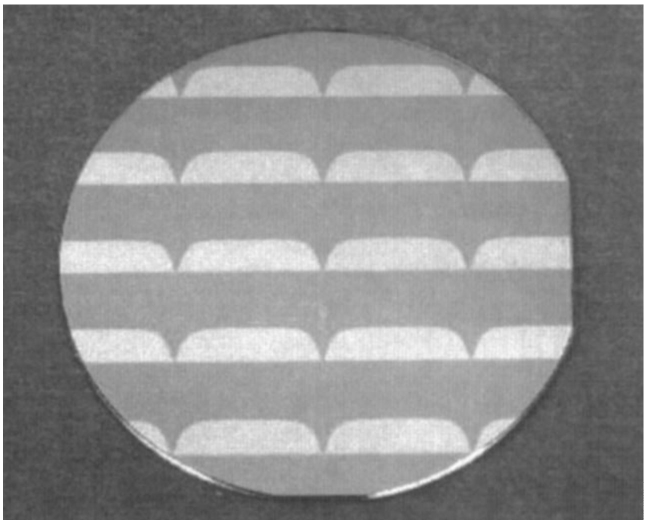

Fig. 1 Photo of an array of multiple PCSS devices on a 2-inch wafer prior to dicing.

III. EXPERIMENT

The goal of the experiment was to determine the maximum hold-off voltage that could be achieved with PCSS devices fabricated on wafers of different thicknesses. Concurrently a second test was done to investigate the performance of the PCSS in different dielectric surroundings. All tests were conducted using a shielded strip line. The strip line had been constructed such that its sides could be removed. This made for the easy removal of the center conductors and/or PCSS device. The strip line was also designed so that it can seal in gas or liquid dielectrics.

Since each of the dielectric materials to be used has a different dielectric constant, the dimensions of the center conductor of the strip line had to be adjusted in order to maintain a 50-Ω circuit impedance. Fig. 2 shows the stripline used in these experiments. The charge line was 31.75 cm in length while the load line is 58.42 cm in length. The cross section of the stripline is rectangular. The relation for determining the proper line impedance for a rectangular shielded stripline can be found in ref. [3].

Three different dielectric media were tested with each of the three PCSS device thicknesses. One gas (SF_6) and two liquid dielectrics (FC-77 and HFE7100) were chosen for these experiments. The dielectric constants for the SF_6 gas, FC-77 and HFE7100 are 1, 1.86, and 7.39, respectfully. Their dielectric strengths are 90 kV/cm, 160kV/cm, and 112kV/cm, respectfully.

Fig. 3 shows a circuit diagram of the experimental setup. The source line was pulse charged to a voltage ranging from 0 volts to greater than 35kV. A resistive probe was used to measure and observe the charge line voltage waveform. This was done to insure that its peak occurred at the same point in time as the laser pulse. This resistive probe was calibrated to a voltage of 35 kV.

A commercial stacked MOSFET switch generated the voltage pulse. To trigger the PCSS device, a high power laser diode was used. The output wavelength was 904 nm. The laser trigger system can produce a 600 W, 20 ns pulse with a 200 ps risetime. A Stanford Research DG535 pulse generator controlled the timing of the laser pulse to coincide with the peak of the charging voltage pulse. The SCD5000 digitizer was used to record the load line pulse.

PCSS device testing was conducted by applying a voltage pulse to the charge line via the MOSFET modulator. The voltage was then increased in increments of 1 kV, until the self-trigger voltage was reached for the PCSS device under test. The voltage was then reduced by 2 kV and applied again to insure that the PCSS device

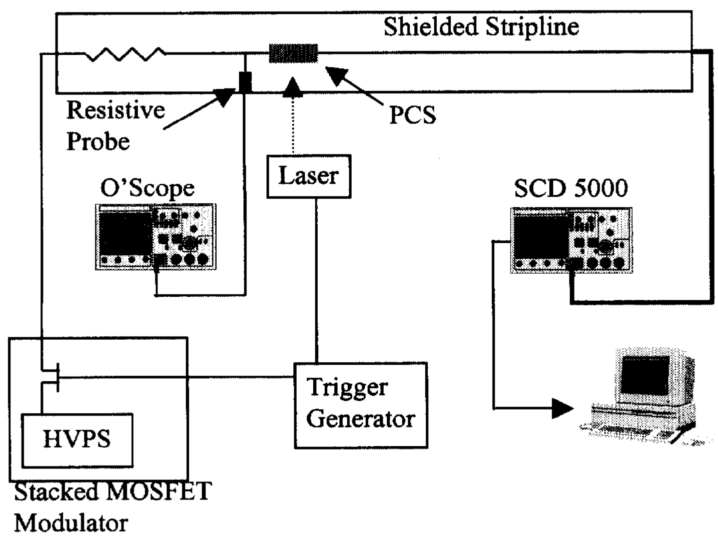

Fig. 3 Circuit diagram of experiment.

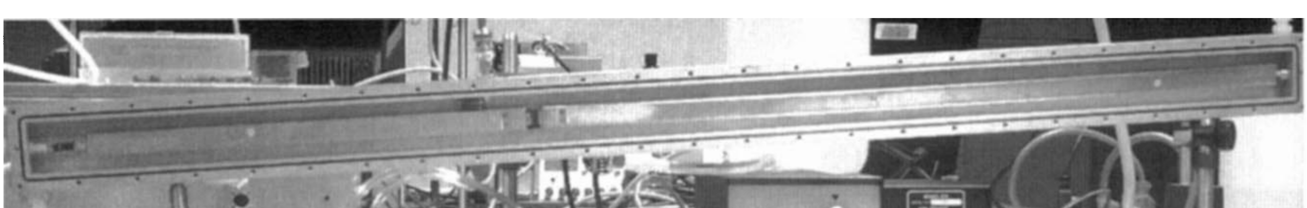

Fig. 2 Picture of shielded strip line with side cover removed.

would not self-trigger. The laser pulse was then used to trigger the PCSS device. The value of the charge line voltage at which time the laser pulse occurred was recorded and the load line waveform was downloaded from the SCD500 digitizer. This procedure was conducted for each device thickness and dielectric combination used.

IV. RESULTS

Figures 4, 5 and 6 summarize the data for each PCSS device thickness in the three dielectric surroundings. The same three PCSS devices were used for all tests. Fig. 4 shows of the results of testing the three PCSS devices in SF_6 gas. As was expected, the hold-off voltage increases with device thickness.

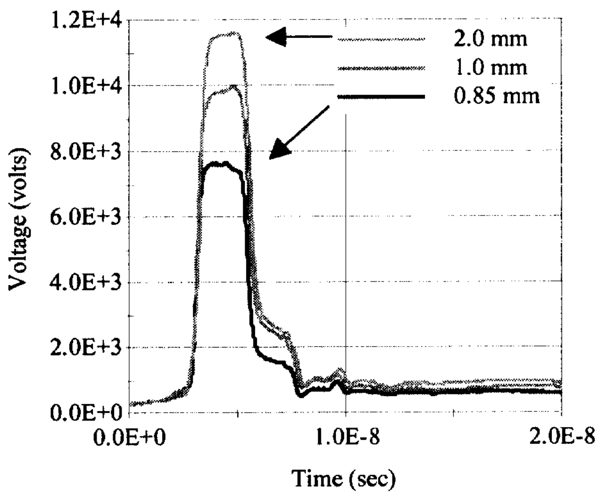

Fig. 4 Load line voltage for SF_6 vs. device thickness

Fig. 5 shows the results of testing the PCSS devices in liquid HFE7100. The hold off voltage again increases with the device thickness. The narrower pulse width for the 2.0 mm thick device is believed to be caused by an internal break down at the output transition of the load line.

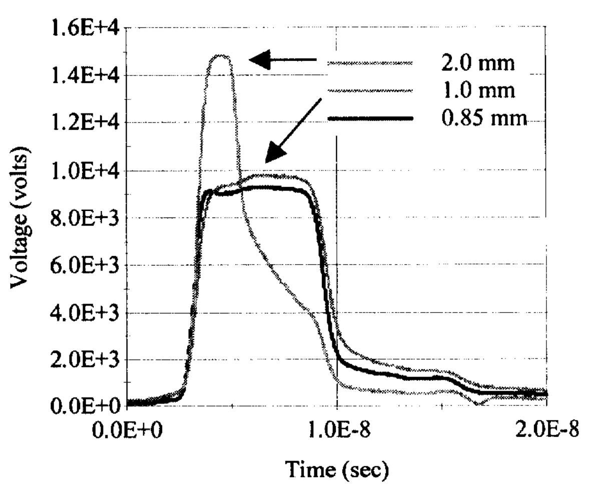

Fig. 5 Load line voltage for HFE7100 vs. device thickness

Fig. 6 shows the results of testing the PCSS devices in liquid dielectric FC-77. Again the hold off voltage increases with device thickness. Also note that the 2.0 mm thick device has a narrowed pulse width. Again, it is believed that this is being caused by an internal break down at the end of the load line.

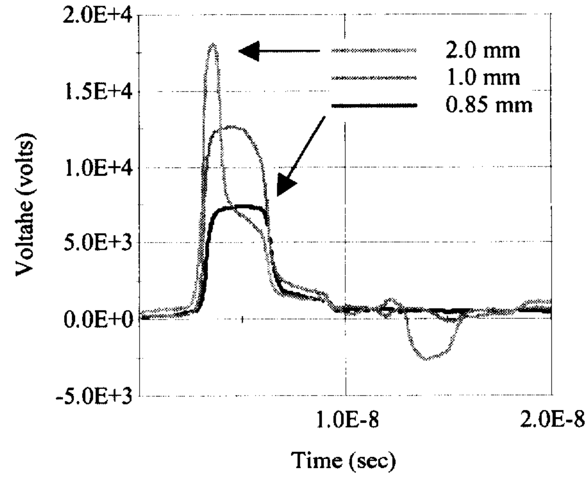

Fig. 6 Load line voltage for FC-77 vs. device thickness

One overlooked consideration is revealed in Fig. 7, which shows a comparison of the stripline (load line) output voltage with a 1.0 mm thick device for the three dielectrics. The variation in pulse width is the result of the different dielectric constants for each of the three dielectrics used. Although the stripline impedance was maintained at 50-Ω for each of the dielectric surroundings, the physical length of the charge lines were the same for all three configurations. The charge line length will be adjusted so that switch lifetime tests will be comparable for the different dielectrics used.

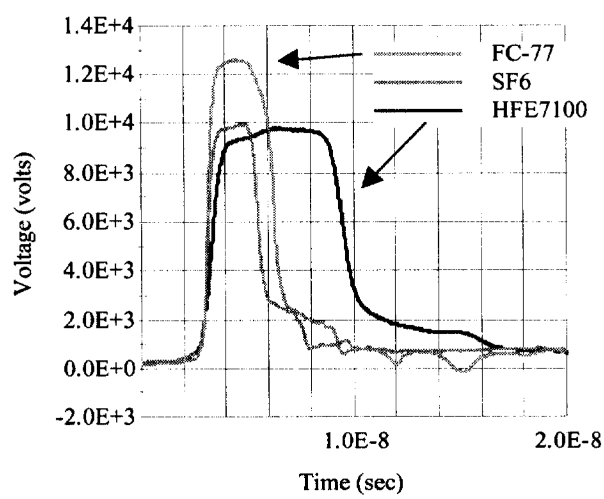

Fig. 7 Load line pulse width vs. dielectric surrounding

Fig. 8 shows a time-expanded view of the rising edge of the signals shown in Fig. 7. The HFE7100 dielectric

imparts a large degradation onto the risetime. The FC-77 dielectric response is more favorable and therefor may be of use without much change to the functional parameter space that this PCSS device can be operated in.

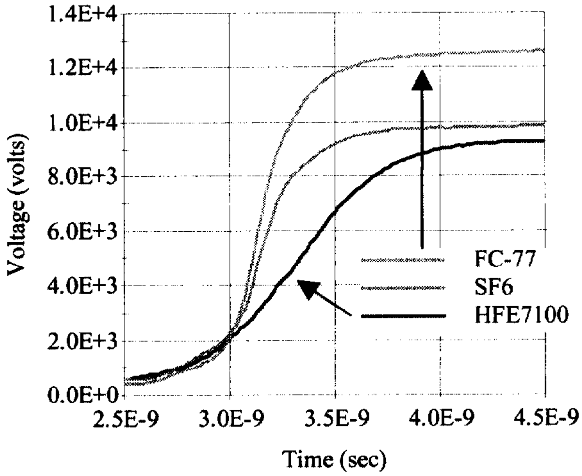

Fig. 8 Load line rise time vs. dielectric surrounding

Tables 1 and 2 tabulate the results obtained during this part of the development phase of the PCSS device. Table 1 is a comparison of hold off voltage (charge line voltage) for each of the dielectrics verses the PCSS device thickness. As can be seen, the table shows that hold off voltage increases with device thickness. Also, in general, higher device hold-off voltages were achieved with the liquid dielectrics. The FC-77 dielectric seems to be the better of the two liquid dielectrics tested.

Table 1. Hold off voltage verse dielectric surroundings and device thickness.

Switch	Hold Off Voltage (kV)		
Thickness	SF_6	HFE7100	FC-77
0.85 mm	16.1	19.3	15.9
1.0 mm	22.4	20.6	28.0
2.0 mm	23.8	30.9	>35.0

Table 2 shows a comparison of PCSS device risetime verses dielectric surroundings and the device thickness. As can be seen in the table, the liquid dielectric FC-77 has the most favorable impact on the risetime. The HFE7100 dielectric delivered the longest risetimes. SF_6 gas gave good results for risetime but has no appreciable heat removal properties. A dielectrics ability to remove heat from the PCSS may come into play when considering device lifetime issues as well as maximum pulse repetition frequency.

Table 2. Risetime verse dielectric surroundings and device thickness.

Switch	Risetime (pS)		
Thickness	SF_6	HFE7100	FC-77
0.85 mm	410	700	590
1.0 mm	540	920	440
2.0 mm	620	810	500

V. CONCLUSIONS

In this phase of the collaborative effort between the AFRL and NSWC for the development of a PCSS, it has been demonstrated that higher hold off voltages can be achieved with the lateral opposed contact geometry by using thicker GaAs substrate material. It has also been shown that using liquid dielectrics can increase the hold off voltage. When the combination of thicker substrates and liquid dielectrics were used, the hold-off voltage went even higher.

The use of liquid dielectrics gives the additional benefits of being able to remove heat from the PCSS device embedded in a pulse forming network of smaller physical size. This may well help to extend the operational parameter space in which the PCSS may be used. Also, with the correct choice of liquid dielectric the risetime can be maintained as compared to operating in SF_6, thus maintaining the bandwidth of the PCSS-commuted impulsive sources.

VI. REFERENCES

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